# METHOD AND APPARATUS FOR TEMPORARILY MAINTAINING A DOWNHOLE FOAM ELEMENT IN A COMPRESSED STATE

## BACKGROUND OF THE INVENTION

**[0001]** The present invention relates generally to methods and apparatuses for controlling fluid flow in a downhole annulus, and more particularly to a method and apparatus for temporarily maintaining a downhole foam element in a compressed state until it needs to expand and fill the annulus to thereby inhibit fluid flow therein.

**[0002]** Very often during recovery of hydrocarbons from a subterranean formation water is produced along with the hydrocarbons. This is undesirable because it necessitates having to remove the water from the production fluid, which is typically expensive. It also creates the problem of having to dispose of the contaminated water, which is particularly problematic in offshore applications. To alleviate the problem, techniques have been developed to isolate regions of the production zone where the water enters the well. These techniques are commonly known as zone isolation. Zone isolation is generally accomplished in long, extended or horizontal completions by installing a section of pipe inside of the production screen section and sealing the isolation pipe both above and below the screen section. This prevents the water from entering the production tubing through the screen in the region of concern.

**[0003]** One drawback of the zone isolation technique, however, is that water can still enter the production tubing. In many cases, water enters the production tubing through the annulus formed between the outer surface of the isolated production assembly section and the inside wall of the casing string (or well bore wall). The annulus acts as a conduit for the water by channeling it to adjacent production screens and in turn into the production tubing.

**[0004]** Recently, a solution to this problem has been proposed. It involves installing a tubular foam element over the outer surface of the production assembly. The tubular foam element fills the annulus between the outer surface of the production assembly and the inside wall of the casing string (or well bore wall). Indeed, the tubular foam element is sized to have an outer diameter that is larger than the inner diameter of the casing string or inner well bore wall so as to cause an interference fit. This allows the tubular foam element to block the annulus from the flow of water in the region of the isolated zone. Although the tubular foam element is permeable, it offers enough flow resistance in the axial direction to significantly reduce, and in some cases nearly eliminate, the seepage of water along the annulus.

**[0005]** The challenge that this proposed solution has presented, however, is how to install the tubular foam element downhole without damaging the element given that its outer diameter exceeds the inner diameter of the inner wall of the well bore.

## SUMMARY OF THE INVENTION

**[0006]** The present invention provides an apparatus for temporarily maintaining a compressible tubular foam element in a compressed state against an outer surface of a downhole sand control device, which comprises a degradable wrap securely fitted around the compressible tubular foam element. The apparatus keeps the compressible tubular foam element in a compressed state so that a production assembly comprising the sand control device and compressible tubular foam element mounted on the sand control device can be placed downhole in a production zone. Once the production assembly is in place adjacent to the production zone, the degradable wrap degrades, thereby causing the compressible tubular foam element to expand filling the annulus formed between the production assembly and the casing string or well bore.

**[0007]** The compressible tubular foam element is permeable to the hydrocarbons and thus during normal operation permits production to flow radially into the production assembly. When water starts to enter a particular zone, a zone isolation step can be performed by installing an isolation pipe inside of the production assembly and sealing at its ends. Although as those of ordinary skill in the art will appreciate other zone isolation techniques may be performed. The compressible tubular foam element remains in the annulus formed between the production assembly and the casing string or well bore and operates to inhibit the normal flow of the water along the annulus.

**[0008]** The degradable wrap according to the present invention is preferably biodegradable and gradually degrades by thermal hydrolysis in the presence of an aqueous solution. It may take the form of a string or tape, which is helically wound around the compressible tubular foam element, but is preferably a tubular sheath made of a woven

degradable polymer. The degradable wrap can be permeable to production fluid by incorporating a material having pores, such as a woven or nonwoven cloth.

**[0009]** In another embodiment, the present invention is directed to a method of maintaining the compressible foam element in a compressed state. The method commences with the step of installing a production assembly downhole within the well bore. The present invention is also directed to the structure of the production assembly, which comprises a base pipe, a sand control device incorporated within, or mounted to, the outer surface of the base pipe, the compressible tubular foam element coaxially mounted to the outer surface of the sand control device, and the degradable wrap securely fitted around the compressible tubular foam element so as to cause the compressible tubular foam element to assume a compressed configuration.

**[0010]** In normal operation, the degradable wrap degrades in the presence of a downhole aqueous solution as more fully explained below, thereby causing the compressible tubular foam element to expand into contact with the casing string or well bore wall. In the event water is detected in a zone adjacent to a section of the production assembly, the method continues with the step of installing an isolation pipe having a top end and a bottom end inside a blank section of the production assembly. Finally, the isolation pipe is sealed to the production assembly at its top end and bottom end or by expanding the isolation pipe so as to cause it to form an interference fit with the production assembly. Preferably, a coil tubing is employed to install the isolation pipe inside of the production assembly and to seal the top and bottom ends of the isolation pipe to the production assembly. However, as those of ordinary skill in the art will appreciate, other techniques may be employed to carry out the steps of the present invention.

**[0011]** Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments which follows.

## Brief Description of the Drawings

**[0012]** The present invention is better understood by reading the following description of non-limitative embodiments with reference to the attached drawings, which are briefly described as follows:

**[0013]** Figure 1 is a cross-sectional view of a production assembly that employs a biodegradable tubular sheath to temporarily contain a compressible tubular foam element against a sand control device in accordance with the present invention.

**[0014]** Figure 2 is a cross-section view of the production assembly shown in Figure 1 after the biodegradable sheath has degraded and the foam element has expanded filling the annulus between the production assembly and the casing string.

**[0015]** Figure 3 is a cross-section view of the production assembly shown in Figure 2 illustrating the condition where water is entering the production tubing through the production assembly and a coil tubing installing an isolation pipe inside of the production assembly.

**[0016]** Figure 4 is a cross-sectional view of the production assembly shown in Figure 2 illustrating the condition where the isolation pipe has been sealed at both ends to the inner surface of the production assembly thereby preventing the water from entering into the production tubing.

**[0017]** Figure 5 is a perspective view of the production assembly shown in Figure 1.

**[0018]** Figure 6 is a perspective view of a production assembly employing a degradable string helically wrapped around the compressible tubular foam element in accordance with another embodiment of the present invention.

**[0019]** Figure 7 is a perspective view of a production assembly employing a degradable tape helically wrapped around the foam element in accordance with another embodiment of the present invention.

**[0020]** It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, as the invention may admit to other equally effective embodiments.

## DETAILED DESCRIPTION OF THE INVENTION

**[0021]** The details of the present invention will now be discussed with reference to the figures. Turning to Figure 1, a multi-sectional production assembly in accordance with the present invention is shown generally by reference numeral 10. The production assembly 10 is shown disposed downhole inside of a casing string 12, which in turn is cemented to the wall of the well bore. The casing string 12 is perforated in the production zone, which is referred to generally by reference numeral 1. As those of ordinary skill in the art will recognize, the present invention has application in open holes as well as those lined with casing string. An annulus 13 is formed between the production assembly 10 and the casing string 12.

**[0022]** The production assembly 10 is formed of a base pipe 14, which is preferably a steel pipe, which has a plurality of openings to allow a production fluid to flow from the production zone 1 into the base pipe 14. The production assembly 10 comprises a sand control device 16, which is mounted to the exterior surface of the base pipe 14 in the region of the openings. The sand control device 16 is generally tubular in shape and is preferably formed of one or more layers of sintered or diffusion-bonded wire mesh screens. However, other known downhole sand control devices may be employed.

**[0023]** The production assembly 10 further includes a compressible tubular foam element 18, which may be formed of any number of materials, including for example, an open cell polyurethane foam. The compressible tubular foam element 18 is preferably permeable enough in the radial direction to permit hydrocarbons to flow through it under normal production conditions, but impermeable enough in the axial direction to offer enough flow resistance to significantly reduce, and in some cases nearly eliminate, the seepage of water along the annulus 13.

**[0024]** The production assembly 10 further comprises a degradable wrap 20, which is securely fit around the outer surface of the compressible tubular foam element 18. In Figures 1-5, the degradable wrap is shown as a tubular sheath, preferably formed of a woven cloth. It may also take the form of a string 120 or tape 220 helically wound around the compressible tubular foam element 18, as shown in Figures 6 and 7, respectively, or be formed of a non-woven material. As those of ordinary skill in the art will appreciate, however, the degradable wrap 20 may take many other forms. Indeed, any configuration capable of temporarily maintaining the foam element 18 in a compressed state is intended to be encompassed by the present invention.

**[0025]** In the embodiment where the degradable wrap 20 takes the form of a tubular sheath, the tubular sheath is pulled over the foam element 18 by way of a tubular mandrel (not shown). The tubular mandrel is preferably designed to collapse the compressible tubular foam element 18 around the sand control device 16 while at the same time pulling the tubular sheath into place.

**[0026]** Nonlimiting examples of degradable materials that may be used in forming the degradable wrap 20 include but are not limited to degradable polymers. Such degradable materials are capable of undergoing an irreversible degradation downhole. The term "irreversible" as used herein means that the degradable material, once degraded downhole, should not recrystallize or reconsolidate while downhole, *e.g.*, the degradable material should degrade *in situ* but should not recrystallize or reconsolidate *in situ*. The terms "degradation" or "degradable" refer to both the two relatively extreme cases of hydrolytic degradation that the degradable material may undergo, *i.e.*, heterogeneous (or bulk erosion) and homogeneous (or surface erosion), and any stage of degradation in between these two. This degradation can be a result of, *inter alia*, a chemical reaction, thermal reaction, a reaction induced by radiation, or by an

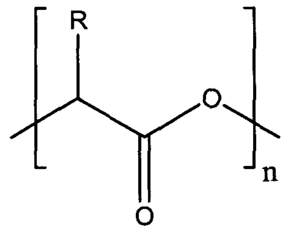
enzymatic reaction. The degradability of a polymer depends at least in part on its backbone structure. For instance, the presence of hydrolyzable and/or oxidizable linkages in the backbone often yields a material that will degrade as described herein. The rates at which such polymers degrade are dependent on the type of repetitive unit, composition, sequence, length, molecular geometry, molecular weight, morphology (*e.g.*, crystallinity, size of spherulites, and orientation), hydrophilicity, hydrophobicity, surface area, and additives. Also, the environment to which the polymer is subjected may affect how it degrades, *e.g.*, temperature, presence of moisture, oxygen, microorganisms, enzymes, pH, and the like.

**[0027]** Suitable examples of degradable polymers that may be used in accordance with the present invention include but are not limited to those described in the publication of Advances in Polymer Science, Vol. 157 entitled "Degradable Aliphatic Polyesters" edited by A.-C. Albertsson. Specific examples include homopolymers, random, block, graft, and star- and hyper-branched aliphatic polyesters. Polycondensation reactions, ring-opening polymerizations, free radical polymerizations, anionic polymerizations, carbocationic polymerizations, coordinative ring-opening polymerization, and any other suitable process may prepare such suitable polymers. Specific examples of suitable polymers include polysaccharides such as dextran or cellulose; chitins; chitosans; proteins; aliphatic polyesters; poly(lactides); poly(glycolides); poly(ε-caprolactones); poly(hydroxybutyrates); poly(anhydrides); aliphatic polycarbonates; poly(orthoesters); poly(amino acids); poly(ethylene oxides); and polyphosphazenes. Of these suitable polymers, aliphatic polyesters and polyanhydrides are preferred.

**[0028]** Aliphatic polyesters degrade chemically, *inter alia*, by hydrolytic cleavage. Hydrolysis can be catalyzed by either acids or bases. Generally, during the hydrolysis, carboxylic end groups are formed during chain scission, and this may enhance the rate of further hydrolysis.

This mechanism is known in the art as "autocatalysis," and is thought to make polyester matrices more bulk eroding.

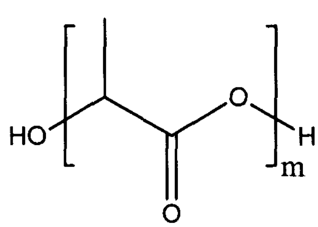
**[0029]** Suitable aliphatic polyesters have the general formula of repeating units shown below:



Formula I

where n is an integer between 75 and 10,000 and R is selected from the group consisting of hydrogen, alkyl, aryl, alkylaryl, acetyl, heteroatoms, and mixtures thereof. Of the suitable aliphatic polyesters, poly(lactide) is preferred. Poly(lactide) is synthesized either from lactic acid by a condensation reaction or more commonly by ring-opening polymerization of cyclic lactide monomer. Since both lactic acid and lactide can achieve the same repeating unit, the general term poly(lactic acid) as used herein refers to formula I without any limitation as to how the polymer was made such as from lactides, lactic acid, or oligomers, and without reference to the degree of polymerization or level of plasticization.

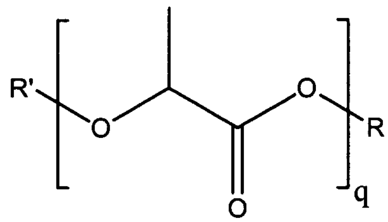
**[0030]** The lactide monomer exists generally in three different forms: two stereoisomers L- and D-lactide and racemic D,L-lactide (meso-lactide). The oligomers of lactic acid, and oligomers of lactide are defined by the formula:



Formula II

where m is an integer $2 \leq m \leq 75$. Preferably m is an integer and $2 \leq m \leq 10$. These limits correspond to number average molecular weights below about 5,400 and below about 720, respectively. The chirality of the lactide units provides a means to adjust, *inter alia*, degradation rates, as well as physical and mechanical properties. Poly(L-lactide), for instance, is a semicrystalline polymer with a relatively slow hydrolysis rate. This could be desirable in applications of the present invention where a slower degradation of the degradable particulate is desired. Poly(D,L-lactide) may be a more amorphous polymer with a resultant faster hydrolysis rate. This may be suitable for other applications where a more rapid degradation may be appropriate. The stereoisomers of lactic acid may be used individually or combined to be used in accordance with the present invention. Additionally, they may be copolymerized with, for example, glycolide or other monomers like ε-caprolactone, 1,5-dioxepan-2-one, trimethylene carbonate, or other suitable monomers to obtain polymers with different properties or degradation times. Additionally, the lactic acid stereoisomers can be modified to be used in the present invention by, *inter alia*, blending, copolymerizing or otherwise mixing the stereoisomers, blending, copolymerizing or otherwise mixing high and low molecular weight polylactides, or by blending, copolymerizing or otherwise mixing a polylactide with another polyester or polyesters.

**[0031]** Plasticizers may be present in the polymeric degradable materials of the present invention. The plasticizers may be present in an amount sufficient to provide the desired characteristics, for example, (a) more effective compatibilization of the melt blend components, (b) improved processing characteristics during the blending and processing steps, and (c) control and regulation of the sensitivity and degradation of the polymer by moisture. Suitable plasticizers include but are not limited to derivatives of oligomeric lactic acid, selected from the group defined by the formula:

Formula III 

where R is a hydrogen, alkyl, aryl, alkylaryl, acetyl, heteroatom, or a mixture thereof and R is saturated, where R' is a hydrogen, alkyl, aryl, alkylaryl, acetyl, heteroatom, or a mixture thereof and R' is saturated, where R and R' cannot both be hydrogen, where q is an integer and $2 \leq q \leq 75$; and mixtures thereof. Preferably q is an integer and $2 \leq q \leq 10$. As used herein the term "derivatives of oligomeric lactic acid" includes derivatives of oligomeric lactide. In addition to the other qualities above, the plasticizers may enhance the degradation rate of the degradable polymeric materials. The plasticizers, if used, are preferably at least intimately incorporated within the degradable polymeric materials.

**[0032]** Aliphatic polyesters useful in the present invention may be prepared by substantially any of the conventionally known manufacturing methods such as those described in U.S. Patent Nos. 6,323,307; 5,216,050; 4,387,769; 3,912,692; and 2,703,316, the relevant disclosures of which are incorporated herein by reference.

**[0033]** Polyanhydrides are another type of particularly suitable degradable polymer useful in the present invention. Polyanhydride hydrolysis proceeds, *inter alia*, via free carboxylic acid chain-ends to yield carboxylic acids as final degradation products. The erosion time can be varied over a broad range of changes in the polymer backbone. Examples of suitable polyanhydrides include poly(adipic anhydride), poly(suberic anhydride), poly(sebacic anhydride), and poly(dodecanedioic anhydride). Other suitable examples include but are not limited to poly(maleic anhydride) and poly(benzoic anhydride).

**[0034]** The physical properties of degradable polymers depend on several factors such as the composition of the repeat units, flexibility of the chain, presence of polar groups, molecular mass, degree of branching, crystallinity, orientation, etc. For example, short chain branches reduce the degree of crystallinity of polymers while long chain branches lower the melt viscosity and impart, *inter alia*, elongational viscosity with tension-stiffening behavior. The properties of the material utilized can be further tailored by blending, and copolymerizing it with another polymer, or by a change in the macromolecular architecture (*e.g.*, hyper-branched polymers, star-shaped, or dendrimers, etc.). The properties of any such suitable degradable polymers (*e.g.*, hydrophobicity, hydrophilicity, rate of degradation, etc.) can be tailored by introducing select functional groups along the polymer chains. For example, poly(phenyllactide) will degrade at about 1/5th of the rate of racemic poly(lactide) at a pH of 7.4 at 55°C. One of ordinary skill in the art with the benefit of this disclosure will be able to determine the appropriate degradable polymer to achieve the desired physical properties of the degradable polymers.

**[0035]** In choosing the appropriate degradable material, one should consider the degradation products that will result, which in this case is a degradable sheath. These degradation products should not adversely affect other operations or components. The choice of degradable material also can depend, at least in part, on the conditions of the well, *e.g.*, well bore temperature. For instance, low molecular weight aliphatic polyesters (*e.g.*, 2,000 – 10,000 mw) have been found to be suitable for lower temperature wells, including those within the range of 60°F to 150°F, and high molecular weight (*e.g.*, 50,000 – 70,000) have been found to be suitable for well bore temperatures above this range. Some stereoisomers of poly(lactide) or mixtures of such stereoisomers may be suitable for even higher temperature applications.

**[0036]** Turning to Figures 1-5, a method of controlling the fluid flow, and more specifically water, in the annulus 13 in accordance with the present invention will now be described. The production assembly 10 in accordance with the present invention is placed downhole in the well bore inside casing string 12 in the region of interest, namely production zone 1, as shown in Figure 1. As also shown in Figure 1, when the production assembly 10 is first placed downhole it has the degradable wrap 20 securely fit around the foam element 18 keeping it in its compressed state.

**[0037]** Over time, as the degradable wrap 20 is exposed to the downhole environment, in particular the aqueous fluids present downhole, it begins to degrade. As the degradable wrap degrades, the compressible tubular foam element begins to expand until it completely fills the annulus 13 between the production assembly 10 and the inside of the well bore, which in this case is lined with casing string 12, as shown in Figure 2. When both the degradable wrap 20 and the compressible tubular foam element 18 are both permeable to the production fluids, the production fluids can be recovered as soon as the production assembly 10 is installed. This is illustrated by the arrows in Figures 1 and 2, which indicate the direction of flow of the production fluids.

**[0038]** In the event that water starts to seep into the production fluid to the point where it detrimentally effects production, the production zone 1 can be isolated from the rest of the well using conventional isolation techniques, which are incorporated into the present invention as follows. A coil tubing 30 lowers an isolation pipe 40 into the inside of the production assembly 10, as shown in Figure 3 in the region of interest. The isolation pipe 40 is basically a section of steel pipe that has an outer diameter smaller than the inner diameter of the base pipe 14. Once the isolation pipe 40 is lowered into the desired position, each of its ends are sealed to the inside of the base pipe 14 using known techniques. The completely installed isolation pipe 40 is shown in

Figure 4, which illustrates how the isolation pipe 40 blocks the flow of water into the production tubing. The compressible tubular foam element 18 creates flow resistance in the axial direction and thereby retards the flow of water along the annulus 13.

**[0039]** Therefore, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit of this invention as defined by the appended claims.